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REVIEW

Algae Based Biofuel and Co-Products - A Review

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Algae accounts for half total primary production at the base of the food chain worldwide as such their importance cannot be over emphasized. These fastest-growing photosynthetic organisms in the world have been discovered from several studies to produce exceptional variety of lipid patterns which could compose as much as 50% of their body mass. In the cell wall matrix of algae are the rich sulphated polysaccharide deposits including fucoidan, porphyran, and alginate promising to develop novel drugs in treatment of cancer and viral infections. Microalgae like the diatoms are also a good source of renewable energy as biofuel (such as biomethane, biohydrogen, bioethanol and biodiesel) which could provide alternative source of energy capable of meeting the global energy demand. Moreover, in the developing countries, little to nothing has been done in exploiting the vast potentials of algae, while its use in China dates back to centuries ago. In conclusion, renewable energy from algae will help to curtail environmental consequences emanating from the exploitation/distribution of fossil fuel.

KEYWORDS: Algae; Biofuel; Renewable energy; Alternative energy; Environment.

INTRODUCTION

The need for renewable sources of energy has created the interest in the cultivation of algae for commercial purposes (Chisti, 2007). Ecologically, algae are the most widespread of the photosynthetic plants, constituting the bulk of carbon assimilation through microscopic cells in marine and freshwater. Algae require abiotic factors such as light, pH, turbulence, salinity and temperature for growth, nutrient quantity and quality. Also, included as part of algal growth requirements are macronutrients (nitrate, phosphate and silicate) and micronutrients [(various trace metals and the vitamins thiamine (B1), cyanocobalamin (B12)] and biotin (Reddy et al., 2005). They can be artificially cultivated and harvested year-round.

Algae contain oils, sugars, and functional bioactive compounds that can be used for commercial products. Pienkos (2007) discovered that algae with 50% lipid content and a dry biomass productivity of 50 g/m²/day can potentially produce 10,000 gallons oil/acre/year. Oil rich microalgae species are the most productive fuel crops, providing 10–100 times higher biomass and oil yield than land oil crops. By comparison, soybeans only produce 48 gallons oil/acre/year (Pienkos, 2007).

Over the ages, society has become dependent upon oil reserves and other fossil resources as a source of fuels, energy, chemicals and materials. With fossil resources declining and climate change becoming of increasing concern, it is vital that renewable and sustainable alternatives are developed.

Recently, many marine resources have been the focus in the search for bioactive compounds to develop new drugs and health foods (Nagai and Yukimoto, 2003). Of all marine organisms, marine algae are a rich source of structurally diverse bioactive compounds with numerous biological activities. In recent times, their importance as a source of new bioactive substances is growing fast. Researchers have shown that these compounds from marine algae exhibit a wide range of biological activities (Barrow and Shahidi, 2008; Wijesekara and Kim, 2010). One particular interesting feature of edible marine algae is their richness in sulphated polysaccharides (SPs). The SPs have applications in microbiology and biotechnology research, food, chemical and pharmaceutical industries (Wijisekara et al., 2011).

Functional polysaccharides such as fucans and carrageenans derivatives produced by seaweeds are known to display various biological properties including anticoagulant, anti-inflammatory, antiviral and antitumoral activities (Costa et al., 2010). In the recent years, SPs, fucoidans have been isolated from different brown algal species such as *Ecklonia cava*, *Ascophylum nodusum*, and *Undaria pinnatifida* (Matou et al., 2002; Athukorala et al., 2006).

HISTORY OF ALGAE AND ALGAE-BASED PRODUCTS

Algae have been part of Chinese life for thousands of years. They have been used as food and cited in their literature for centuries (Borowitzka, 1999). In recent times, the uses of algae have gained major application in Spain (Ordonez et al., 2010). The first reported use of microalgae by humans dates back to the Chinese who used Nostoc as an emergency food source some 2000 years ago during famine (Spolaore et al., 2006). However, it is only about 50 years ago that the commercial exploitation of eukaryotic algae started. This initially concentrated on algal biomass as a source of protein and the systemic examination of algae for biologically-active compounds and pharmaceuticals (Harwood and Guschina, 2009). Formal taxonomic studies of Chinese algae were initiated by foreign scientists about 200 years ago and by Chinese phycologists about 90 years ago (Tseng, 2004). The algae are typically grown on long-line systems out at sea. Around 15 million wet tonnes are produced each year with activity largely limited to Eastern Asia (Olaizola, 2003). Within Europe, commercial production of macroalgae is restricted to France and Spain although experimental research is being performed in the UK, Norway, Ireland and Portugal (Spolaore et al., 2006).

CLASSIFICATION

The classification of algae is complex and somewhat controversial (Radmer, 1996). There are four types of algae; unicellular, colonial, filamentous and multicellular. Algae belong to domain Eukaryota, Kingdom Plantae with seven Phyla based on colour, type of chlorophyll, food storage substance and cell wall composition namely: Chlorophyta (greenalgae), Rhodophyta (red algae), Phaeophyta (brown algae), Magnoliphyta (flowering

plants-sea grasses and mangroves), Bacillariophyta (diatoms), Dinoflagellata (dinoflagellates), and Oomycota which are the watermolds (Harwood and Guschina, 2009).

CHARACTERISTICS OF ALGAE

Algae are simple, plant-like organisms but do not have roots, stems, and leaves. There are over 200,000 alga species distributed throughout the world (Guiry, 2012). Algae are typically photosynthetic, namely fixing CO_2 in the presence of sunlight to manufacture their own food, but some are heterotrophic with no requirement of light, assimilating organic compounds such as glucose and acetic acid as carbon sources (Bruton et al., 2009). Algae, being ubiquitous can be found in all aquatic habitats i.e. in rivers, streams, seawater, freshwater, and even wastewater (Wagner, 2007). Algae have been identified as the most diverse assemblage of organisms that can be easily sampled and identified readily to species or variety (Stevenson and Smol, 2003).

Most of the current research and development efforts have made microalgae a focal-point due to their oil content and high growth rate (Ahmad et al., 2013). Algae contain oils, sugars, and functional bioactive compounds that can be used for various commercial products. Recently, a lot of attention has been given to cultivation of microalgae as —energy‖ crop aiming to replace traditional oil crops for bio-oil and biodiesel production.

Algae need light, carbon dioxide, water, and nutrients (macro and micro) for photosynthesis. Sunlight, air, and seawater or waste water can basically meet the requirements for algae growth. However, optimal cultivation conditions can achieve better algae growth (Agwa et al., 2012). For example, light wavelengths between approximately 450 nm (blue) and 650 nm (red) are usually preferred (Marsh, 2008).

The light intensity is important as photo inhibition occurs after exposure to too intensive light. For some algal species a dark cycle is important for processing photosynthates produced in a light cycle for lipid production. The typical temperature range for algal cultivation is 25–35°C. Carbon dioxide supplied at an optimal concentration of 350-1000 ppm and flow rate, micro nutrients, macro nutrients and salinity of water are all very important for maximum algae growth.

The pH of the culture media should be preferably maintained between 7 and 9. Mixing is essential to make sure algae are evenly exposed to light and nutrients.

METABOLIC DIVERSITY

Algae contain diverse and unusual bio-chemical compounds, such as fats, sugars, pigments, and bioactive compounds. The diversity of algal metabolism is obvious in some unusual ways, such as:

Toxins

Dinoflagellates produce toxins known as breve toxins which cause a human infection called neurotoxic shellfish poisoning, resulting from the ingestion of molluscan shellfish containing this compound (Watkins et al., 2008). A bioactive compound known as okadaic acid was initially isolated from sponges; however, it has been demonstrated from subsequent work that the okadaic acid compounds are produced by algae (dinoflagellates) which are closely associated with the sponges (Kacem et al., 2010).

Oil from Algae

Microalgae that are able to survive heterotrophically, use exogenous carbon sources as a source of chemical energy, which the cells often store as lipid droplets (Ratledge, 2004). *Chlorella protothecoides* cultivated heterotrophically has been shown to accumulate as much as 55% of its dry weight as oil, compared to only 14% in cells grown photo-autotrophically (Wu and Miao, 2006).

Sulphated polysacchharides

Now-a-days, the field of marine natural products has become more mind-blowing. In the cell wall of sea weeds are varied biologically active components with diverse structures and interesting functional properties (Shibata et al., 2008; Kim and Bae, 2010). The bioactive components of seaweeds include polyphenols, peptides and polysaccharides, and the likes. Most of these active compounds are found to be useful functional ingredients with a lot of health benefits. Polysaccharides from seaweeds create an expansion and gives economic importance to global industries. They are used in food, pharmaceuticals and other products for human consumption.

Over the last decade, bioactive SPs isolated from brown seaweeds have attracted significant attention in the fields of biochemistry and pharmacology.

Functional SPs such as fucans and alginic acid derivatives produced by brown seaweeds, exhibit different biological properties including anticoagulant, anti-inflammatory, antiviral and antitumoral activities (Lee et al., 2008; Costa et al., 2010).

TYPES OF BIOFUELS

Biofuels can be broadly divided into two. Thus: First generation biofuels are those produced from edible sources such as sugar, starch, vegetable oils, corn, and sorghum. They are referred to as conventional biofuels which has traversed ages (Schenk et al., 2008). Second generation biofuels are those produced from sustainable free energy which is produced from non-food crops or non-edible waste products. Other second generation biofuels include those sourced from algae, bio-hydrogen, bio-methanol and biogas etc. Several other researchers are working on tertiary generation biofuel which could be deemed to include: solid biofuels from wood, saw-dust, grass trimmings, domestic refuse, charcoal, agricultural waste, non-food energy crops and dried manure and those produced from lignocellulose sources (Huang et al., 2009). With so many sources of biofuels, why the advocate for algae-based biofuels?

WHY ALGAE-BASED FUEL?

Microalgae have multiple characteristics that enhance their use as a biofuel source. In recent years, use of microalgae as an alternative biodiesel feedstock has gained renewed interest from researchers, entrepreneurs and the general public. Energy from algae could provide alternative source of energy that may be capable of meeting the global demand on energy (Singh et al., 2010; Demirbas and Demirbas, 2011).

Algae offer many potential advantages. Microalgae are microscopic in size and can be grown continuously in well-mixed liquid cultures (Dismukes et al., 2008). They have a high oil content and rapid biomass production, algae can potentially produce 10,000 gallon/ acre/year significantly higher than soybeans and other oil crops (Priyadarshani and Rath, 2012). Many microalgal species can be induced to accumulate substantial quantities of lipids, often greater than 60% of their dry biomass (Sheehan et al., 1998). Conventional terrestrial plants are less efficient in capturing light, converting less than 0.5% of the solar energy received at typical mid latitudes into plant biomass; on the other hand, the photosynthetic efficiency of microalgae can exceed 10% (Li et al., 2008). Also, microalgae require far less land, they do not compete with traditional agriculture because they can be cultivated in large open ponds or in closed photobioreactors located on non-arable land. They can grow in a wide variety of climate and water conditions; they can utilize and sequester CO_2 from many sources (Rosenberg et al., 2008). The most significant distinguishing characteristic of algal oil is its yield and hence its biodiesel yield (Ahmad et al., 2013). Also according to Ahmad et al., (2013) the yield (per acre) of oil from algae is over 200 times the yield from the best-performing plant/vegetable oils.

They can be converted to liquid fuels via simpler technologies than is needed to convert cellulose, and have other uses that fossil fuels do not provide (Dismukes et al., 2008). They can be processed into a broad spectrum of products including biodiesel via trans-esterification, green diesel and gasoline replacements via direct catalytic hydrothermal conversion, and catalytic upgrading. Further processing can take place thus; bioethanol via fermentation, methane via anaerobic digestion, heat via combustion, and bio-oil and biochar via thermochemical conversion (Aminu et al., 2013). These ways of converting microalgal biomass to energy sources can be divided into biochemical conversion, chemical reaction, direct combustion, and thermochemical conversion. Thus, microalgae can provide feedstock for renewable liquid fuels such as biodiesel and bioethanol (Georgianna and Mayfield, 2012).

Algal biodiesel can be easily used in unmodified diesel engines, and it has valuable advantages over conventional diesel fuel because it is renewable, biodegradable and releases lower emissions of sulfur oxides and particulates when burned (Carere et al., 2008).

COMPOSITION OF ALGAE

Biofuels from microalgae are produced from the lipid content of the algal cells, which has the potential to serve as the feedstock for many high energy density transportation fuels. The fuels that could be derived include: biodiesel, green diesel, green jet fuel and green gasoline. The remaining algal biomass

(leftover) can also be converted to biofuels through either biochemical or thermochemical conversion routes (Pienkos, 2009).

All algae contain proteins, carbohydrates, lipids and nucleic acids in diverse proportions, while the percentages vary with the type of algae and the cultivation conditions. Some algae types could accumulate 40-70% or more of their overall mass by fatty acids. They have the potential to produce more oil per acre than any other feedstock being used to make biodiesel (Becker, 1994; Demirbas, 2009).

PROCESSES INVOLVED IN CONVERSION OF ALGAE TO VARIOUS PRODUCTS

BIODIESEL

According to Shi et al., (2019), algae biofuels production involves complicated cultivation, harvesting, dewatering, oil-extraction, and conversion steps. For the growth of algae for biodiesel production, processes to be followed are:
(1) Species selection (2) Cultivation of algae (3) Harvesting/drying (4) Lipid extraction (5) Transesterification. These steps are discussed further as below:

Species Selection

Many screening programs abound around the world surveying algal species in different locations for suitable strains, often building on the pioneering studies in the Aquatic Species Program during the 1980s and 1990s (Sheehan et al., 1998). Complementing this is more recent research work based on a few number of fast-growing microalgal species found to accumulate substantial quantities of lipids, though under specific conditions. Within the green algae, typical species include *Chlamydomonas reinhardtii*, *Dunaliella salina*, and various *Chlorella* species, as well as *Botryococcus braunii*, which are slow growing but contains over 60% lipid, much of which is stored in the cell wall (Metzger and Largeau, 2005). Other important algal groups include the diatoms; *Phaeodactylum tricornutum*, *Thalassiosira pseudonana*, and other heterokonts including *Nannochloropsis* and *Isochrysis* spp.

Cultivation of Algae

Algae can be cultivated in open ponds, seashore, and waste-water and artificially in constructed photobioreactors. All of the above except the photo-bioreactor has the disadvantage of contamination with other organisms. Cultivating algae in an enclosed bioreactor, in which the system is strictly controlled and no contamination occurs, is a replacement to overcome the problems with open systems. Clemens (2009) noted that the high expenditure and operating costs are the main problem for the enclosed bioreactor. For algae cultivation in production of high value fatty acids (e.g., eicosapentaenoic acid [EPA] and docosahexaenoic acid [DHA]) enclosed photo-bioreactors should be considered. The advantages of photo-bioreactors are quite clear: they offer cultivation under a wide variety of conditions or prevent, to some extent, outcompeting of the production strain by other algae or contamination with undesirable microorganism or grassers. The main benefits of closed bioreactor systems include higher productivities and the prevention of water loss by evaporation (Clemens, 2009).

Harvesting Algae

Separating algae from water has always been faced with several difficulties, as the density of microalgae is close to that of water. Flocculation can lead to the formation of flocks (Uduman et al., 2010). Microalgae cell harvesting generally involves two major solid-liquid (algae-water) separation steps. The first step, flocculation, aggregates the algal cells and improves the effectiveness of the second step. Several methods such as filtration, centrifugation, or gravity sedimentation can be used in the second step for microalgae biomass harvest. Filtration is suitable for the large size microalgae but has the disadvantage of low efficiency while centrifugation can harvest most kinds of microalgae but can damage the cell membranes due to high centrifugation speed and shear stress (Lee et al., 2009). Gravity sedimentation is generally used for sewage-cultured algae recovery, but is time consuming and requires space for settling ponds or tanks. Compared with other recovery methods, microalgae biomass from sedimentation generally has a much higher moisture content, which can substantially increase the cost of biomass drying for the further downstream process. Therefore according to Lee et al., (2009) filtration or centrifugation preceded by flocculation-flotation is generally adopted as the method for microalgae

biomass recovery. However, Bejor et al., (2013) concluded from their research that for most algae sizes commonly found in water and wastewater samples, efficient harvesting could be achieved using the stretch-cotton fabric material for filtration.

Drying

Algae can be dried for use as fuel and food. Drying such a delicate substance is very challenging and requires one to be innovative. The most successful algae drying techniques eliminate destructive elements like high heat from the drying process. When it is dried directly under the sun, chlorophyll is degraded and it also causes the materials to be overheated coupled with the fact that the method is dependent on weather (Shelef et. al., 1984). Shelef *et. al.* further deduced that applying solar radiation indirectly prevents overheating of the materials but the drying rate is higher while the end product is less attractive. It can be freeze- dried which involves freezing it completely. Once frozen, algae can be transferred to a vacuum chamber where the pressure is reduced. At this pressure, the ice cannot melt. The ice is then evaporated by passing the liquid stage of evaporation. The vapour is collected on an extremely cold condenser and removed out of the vacuum chamber. The algae, now left completely dry with all nutritious value preserved because only the water content is removed. Other methods have been utilized in drying microalgae such as *Chlorella*, *Scenedesmus* and *Spirulina*, where the most common include spray-drying, drum drying and sun-drying (Richmond, 2004). Due to the high-water content of algal biomass, sun-drying is not a very effective method for algal powder production and spray-drying is not economically feasible for products, such as biofuel or protein. However, Shelef et. al., concluded that scale of operation and the use for which the dried product is intended would be great prerequisites in choosing the right drying method.

Oil Extraction

Methods used to extract oil from algae include mechanical systems, thermal, plasma, chemical and microwave techniques. Most of the traditional methods do not offer the long-term solutions (Xu et al., 2006). Suitable solvents can be used to extract algal oil (Ahmad et al., 2013). Releasing the lipids from their intracellular location has to be done in the most energy-efficient and economical way possible, avoiding the use of large amounts of solvent, such as hexane. A major requirement is that the oil be released and extracted without much contamination by other cellular components, such as DNA or chlorophyll. There are various approaches based on selective decomposition of the cell wall, possibly using enzymes, and novel methods minimizing the use of solvents as described by Aminu et al., (2013).

Trans-esterification

Transesterification is a multiple step reaction, which includes three reversible steps. Triglycerides are converted to diglycerides, then diglycerides are converted to monoglycerides, and monoglycerides are then converted to esters (biodiesel) and glycerol (by-product) (Mata et al., 2010). Alcohols, such as methanol reacts with the algal oil in the presence of a base catalyst to produce glycerol and biodiesel. This is the most common method of converting algal oil to biodiesel and yields monoalkyl esters of algal oil, fats and vegetable oil. The methyl ester produced by transesterification of vegetable oil is low in viscosity and improved heating value in comparison to those of pure vegetable oil which results in shorter ignition delay (Demirbas, 2010).

BIOETHANOL

Two methods are usually adopted for production of bioethanol from biomass. The first one is biochemical process (fermentation) and the other is by thermo-chemical process known as gasification (Nigam and Singh, 2010). The recent attempts for producing ethanol are focusing on microalgae as a feedstock for fermentation process. Microalgae are rich in carbohydrates and proteins that can be used as carbon. Bioethanol production by fermentation has not been reported extensively. The most recent work on bioethanol production by fermentation has been reported by Harun et al., (2010). They experimented on the suitability of microalgae (*Chlorococum* spp.) as a substrate, using yeast for fermentation. A productivity level of around 38 wt.% has been reported by the authors, which supports the suitability of microalgae as a promising substrate for bioethanol production. Moen (1997) in his doctoral work, has authenticated that brown seaweed produces higher bioethanol compared to other algal species. The technology for the commercial production of bioethanol from microalgae is however, still being unraveled and is

being further researched.

BIOMETHANE

Bioethanol production by fermentation is useful also for simultaneous production of biogas. Biogas produced from anaerobic microorganisms by anaerobic digestion mainly consists of a mixture of methane (55–75%) and CO_2 (25–45%). Methane from anaerobic digestion can be used as fuel gas and also converted to generate electricity (Holm-Nielsen et al., 2009). Left-over biomass from anaerobic digestion can further be reprocessed to make fertilizers. This would encourage sustainable agricultural practices in providing greater efficiencies and reduce algae production costs in addition to being renewable and sustainable. As a result of absence of lignin and lower cellulose, microalgae displays good process stability and high conversion efficiency for anaerobic digestion (Vergara-Fernandez et al., 2008). The biogas production from this anaerobic digestion process is mainly affected by its organic loadings, pH, temperatures, and retention time in reactors. Basically, long solid retention time and high organic loading rate give significant results in high methane yield (Chynoweth, 2005). Also, anaerobic digestion can operate in either mesophilic (35.8°C) or thermophilic (55.8°C) conditions.

Hydrogen from Algae

Gasification involves applying heat under pressure in the presence of steam and a controlled amount of oxygen. The biomass is chemically broken apart by the gasifier‘s heat, steam and oxygen, instituting chemical reactions that produce a synthesis gas or ―syngas‖ which is a mixture of predominantly hydrogen, carbon-dioxide and carbon-monoxide. The carbon monoxide is then reacted with water to form carbon-dioxide and more hydrogen.

Co-Products from Algae

Manufacturing products from algae, ranges from low-technology ocean farming to cutting-edge pharmaceutical-like production. The main algal stock are currently produced by the seaweed industry which is based on the harvest and use of macroalgae (i.e., seaweeds), chiefly brown algae, the largest and most apparent of the macroalgae, and red algae, a multifarious group of algae (Sinead et al., 2011).

MICROALGAE AND HUMAN FOOD

Microalgae are a rich source of carbohydrates, protein, enzymes and fiber containing several vitamins and minerals like vitamin A, C, B1, B2, B6, niacin, iodine, potassium, iron, magnesium and calcium (Priyadarshani and Rath, 2012). Being such a rich source of essential nutrients, they are a major source of food, especially in Asian countries like China, Japan and Korea (Priyadarshani and Rath, 2012). Green micro-algae have been used as nutritional supplement or food source in Asian countries for hundreds of years. These days, they are consumed throughout the world due to their nutritional value (Colla et al., 2007; Ogbonda et al., 2007). The green algae (Chlorophyceae) *Chlorella vulgaris*, *Haematococcus pluvialis*, *Dunaliella salina* and the *Cyanobacteria Spirulina maxima* are some of the most biotechnologically relevant microalgae and are widely commercialized and used, mainly as nutritional supplements for humans. *Spirulina platensis*, a blue-green alga is gaining popularity worldwide as a food supplement, it has been experimentally proven to be an excellent source of proteins (Colla et al., 2007), polyunsaturated fatty acids (Sajilata et al., 2008), pigments (Rangel-Yagui et al., 2004; Madhyastha and Vatsala, 2007), vitamins and phenolics (Colla et al., 2007; Ogbonda et al., 2007).

Foods from Macro-algae

In these cases, the stock is the biomass itself, and not chemicals extracted from the algae. Any postharvest processing serves the sole purpose of tidying and conserving the inherent character of the alga.

Nori

The major algal food in the world today is nori, the thallus (blade) of certain species of the red macroalga *Porphyra* (this is shown in Figure 1). Nori is a main constituent of sushi, a Japanese food that is becoming increasingly popular in the West (Radmer, 1996). Due to its history and economic success, this product provides a good example of the macroalgal production procedures currently available. In processing nori, modern techniques

Figure 1. Nori, used to wrap rolls of Sushi.

Figure 2. Food salad, Wakame.

introduced in the 1960s have provided the means to rapidly increase production yields (Oohusa, 1993). Nori cultivation is a type of farming in which seed-like propagules, called conchospores, are seeded onto nori nets, which are hung in sheltered ocean areas (Radmer, 1996). Also according to Radmer, nori cultivation before the 1960's was limited to shallow, sandy bays, where the nori nets could be hung between poles stuck in the bottom. There are many available nori products: of these, toasted nori sheets are the largest product segment (Oohusa, 1993). With a market value of approximately $2 billion and a product volume of 40,000 tons per year (Jensen, 1993), nori represents the most lucrative algal product group at the present time. Although nori is primarily consumed in Japan, Korea, and China, sales in other countries are rapidly increasing-US sales in 1991 were estimated to be $20- $25 million (Merrill, 1993).

Wakame

Another major algal food product is wakame, derived from a brown alga known as *Undaria pinnatifida* (Figure 2). This macroalgal product has been cultivated commercially since the mid-1950s (Yamanaka and Akiyama, 1993). Wakame is produced mainly in Japan, Korea, and China, with Korea being the major producer. It is more extensively processed after harvest than most other macroalgal biomass products. The most accepted wakame product is boiled and salted, resulting in the green product most preferred by consumers (Radmer, 1996). As with nori, the primary market for wakame products is Japan, where it is available in many forms (e.g., salted or dried cut) and is used as an ingredient in soups, salads, noodles, and the like. As of 1990, roughly 20,000 tons, with a market value of $600 million, were sold annually (Radmer, 1996).

ALGAE FOR PHARMACEUTICALS

Anti-coagulent Activities

Anticoagulants are substances that prevent coagulation; in other words, they stop blood from clotting (Desai, 2004). Marine algae are a rich source of SPs with novel structures, and these compounds have anticoagulant properties (Mestechkina and Shcherbukhin, 2010). The anticoagulant activities of seaweeds SPs hinges on having preferably two sulphate groups and a glycosidic linkage on the pyranose ring (Ciancia et al., 2010). This enables them to co-relate with the basic groups in proteins. Various anticoagulant polysaccharides, especially from red and brown seaweeds have been isolated and characterized (Mao et al., 2006; De Zoysa et al., 2008). The ability of SPs to interfere with biological systems has a longstanding record. (Huynh et al., 2001).

Antiproliferative, Antitumor and Anticancer Activities

Crude extracts and pure compounds from marine organisms have been the object of many investigations during the search for natural anticancer compounds, (Moreau et al., 2005). Lately, it has been reported that fucose-rich SPs isolated from brown seaweeds exhibited anticancer activity, which is one of the most vital biological activities of seaweeds. Daily seaweeds intake reduces rectal (Kato et al., 1990), benign and neoplasis (Aceves et al. 2005; Garcia-Solis et al., 2005) as well as breast cancer risks (Yoon et al., 2010). Numerous kelps adequately diminished mammary tumors (Funahashi et al., 2001).

Fucoidan, porphyran, and alginate which are rich SPs in the cell wall matrix of algae, are now undergoing intensive research to develop novel drugs in treatment of cancer and viral infections (Paulsen, 2002; Ponce et al., 2003; Adhikari et al., 2006).

Antiviral Activity

The potential antiviral activity of polysaccharides from marine algae was first observed by Gerber et al., (1958), who revealed that the polysaccharides extracted from *Gelidium cartilagenium* (Rhodophyceae) protected the embryonic eggs against Influenza B or mump virus. Sulphated polysaccharide showed antiviral effects on HSV-1, HSV-2, HCMV, HIV-1, RSV, influenza virus and bovine viral diarrhea virus. The antiviral activities involve: (i) interacting synergistically with the target cell to block entry of virus (Mc Clure et al., 1991; Pujol et al., 2002), (ii) inhibiting virus adsorption to cells by competing with virus binding to cell (Duarte et al., 2004).

ALGAE AS BIOFERTILIZER

Microalgae are used in agriculture as biofertilizers and soil conditioners. Most cyanobacteria are able to fix atmospheric nitrogen and are effectively used as biofertilizers. Cyanobacteria play an important role in the maintenance and build-up of soil fertility, thereby increasing rice growth and yield as a natural biofertilizer (Song et al., 2005). The importance of cyanobacteria in rice cultivation is directly related with their ability to fix nitrogen and other positive results for plants and soil. After water, nitrogen is the second limiting factor for plant growth in many fields and deficiency of this element is catered for by fertilizers (El Gamal, 2010).

According to Song et al., (2005), with the use of Blue green algae (BGA), apart from increase in yield and saving of fertilizer nitrogen, the soil physico-chemical properties also improved. There is measured hype of residual soil nitrogen and carbon improvement in soil pH and electrical conductivity. In terms of protein content, the grain quality improves. Blue green algae belonging to genera Nostoc, Anabaena, Tolypothrix and Aulosira fix atmospheric nitrogen and are used as inoculants for paddy crop grown both under upland and low land conditions (Malik et al., 2001). Anabaena in association with water fern (Azolla) contributes nitrogen up to 60 kg/ha/season and also enriches soils with organic matter (Song et al., 2005). A variety of free-living cyanobacteria are now identified as efficient components of cyanobacterial biofertilizers. In addition to contributing nitrogen, cyanobacteria also benefit crop plants by producing various growth-promoting substances. Examples include; cyclic polyethers that have potent biological activities (Moore and Entzeroth, 1988; El Gamal, 2010).

ALGAE FOR CLEAN UP

Some manufacturing plant wastewater (enzyme, or food industries) seems to be quite promising for microalgae growth combined with biological cleaning. This allows nutrition of microalgae by using organic compounds (nitrogen and phosphorous) available in the wastewater, not containing heavy metals and radioisotopes (Aslan and Kapdan, 2006). Additionally, microalgae can attenuate the effects of sewage effluent and industrial sources of nitrogenous waste such as those emanating from water treatment or fish aquaculture and consequently contributing to biodiversity (Mata et al., 2010). Moreover, removing nitrogen and carbon from water, microalgae can help reduce the eutrophication in the aquatic environment. The alga, Euglena is used for bioremediation of heavy-metal contaminated water (Krajčovič, et al., 2015).

Aslan and Kapdan (2006) used *C. vulgaris* for nitrogen and phosphorus removal from wastewater with an average removal efficiency of 72% for nitrogen and 28% for phosphorus. Other widely used microalgae cultures for nutrient removal are *Chlorella* (Lee and Lee, 2001) and *Spirulina* species

Figure 3. Algal bloom on a beach.

(Olguin et al., 2003).

MICROALGAE AND COSMETICS

The pigment embedded in microalgae is specific for species. Components of algae are frequently used in cosmetics as thickening agents, water-binding agents, and antioxidants. Some microalgal species are established in the skin care market, for example *Arthrospira* and *Chlorella* (Stolz and Obermayer, 2005).

Microalgae extracts can be found in face and skin care products (e.g., anti-aging cream, refreshing or regenerant care products etc.). Microalgae are also used in sun protection and hair care products. Species typically used for cosmetics are *Alaria esculenta*, *Chondrus crispus*, *Mastocarpus stellatus*, *Spirulina platensis*, *Nannochloropsis oculata*, *Ascophyllum nodosum*, *Chlorella vulgaris* and *Dunaliella salina*. Microalgae are a polyphyletic and biochemically diverse assemblage of chlorophyll a' containing microorganisms capable of oxygenic photosynthesis.

They are majorly found in aquatic environments with observed high levels of ultraviolet (UV) radiation. Certain microalgae produce organic metabolites, such as scytonemin, sporopollenin and mycosporine-like amino acids, which protect them from UV radiation at the same time allowing visible radiation involved in photosynthesis to pass through (Spolaore et al., 2006).

DRAWBACKS IN THE USE OF ALGAE

Some species of algae produce harmful toxins which are hazardous both to animals and humans. An example is brevetoxins which cause Neurotoxic Shellfish Poisoning (NSP). This poisoning is caused through the intake/ingestion of molluscan shellfish contaminated with brevetoxins, produced by the marine dinoflagellate, *Karenia brevis* (Trainer et al., 2003). This causes the ocean to appear red, brown, or simply darkened due to the dense aggregation of cells leading to massive fish kills and mortalities in marine mammals and sea birds as seen in Figure 3. The largest reported outbreak of NSP in the US occurred in North Carolina after *K. brevis* was carried into that region from Florida.

CONCLUSION

The benefits of biofuel production or development are numerous and very crucial to the swift development of the economy of any nation. Biodiesel can be used in car engines even when it is not yet refined. It can also be blended with normal diesel and used in cars. It is a source of foreign earnings since it can be exported as clean fuel to every part of the world. Biodiesel from algae can be used as a substitute for or as an additive to diesel fuel thus providing an alternative source of energy for diesel-powered engines. Since, it is a renewable domestically furnished liquid fuel it can reduce countries' dependence on oil importation. It is currently not subject to market forces and can be readily tapped unlike petroleum products.

Biodiesel is reputed as the most valuable form of renewable energy that can be used directly in any existing, unmodified diesel engine. Production of biofuel can lead to development of new industries, new jobs, new markets, new technologies, etc. The foreign earnings could be channeled towards the development of other sectors of the economy especially health and education sectors.

SPs from algae should be used as active ingredients for preparation of nutraceutical, cosmeceutical, pharmaceutical products and functional ingredients. Biofuel generates fewer emissions of carbon monoxide, particulates, and toxic chemicals unlike fossil fuel e.g., gasoline and diesel with high emissions that cause smog, aggravate respiratory and heart diseases and contributes to thousands or even hundreds of thousands of premature deaths each year. Biodiesel produces significantly less carbon dioxide and much less sulphur dioxide emissions, provides reduction in cancer risk (Packer, 2009; Mata et al., 2010). As

such, the uptake of carbon from atmosphere by algae reduces the effects of global warming.

Biodiesel is as biodegradable as sodium-chloride. It is environmentally friendly and ideal for heavily polluted cities like Lagos and Port-Harcourt (Patrick et al., 2013). It is cheaper than mineral oil diesel and capable of extending the life-span of engines; and a means of conserving natural resources. According to the International Energy Agency, biofuels have the potential to meet more than a quarter of world demand for transportation fuels by 2050 (IEA, 2011). It can be sourced from various means including algae, making its prospects almost limitless. Algae biofuels have now generated plenty of interest with over 150 companies worldwide (Deng et al., 2009). The European Union (EU) for example intends to replace 10% of all transportation fossil fuels with biofuels by 2020 (Rosch and Skarka, 2009).

The merging of cultivation, harvesting, drying, oil extraction and conversion technologies of algae can aid stakeholders in identifying more likely ways for developing algal biofuel, and also show key areas where more work is needed to solve current restraints (Shi et al., 2019).

In recent times, Nigeria has shown interest in biofuel especially in the area of renewable energy by collaborating with top renewable energy companies from Belgium and Israel (Aminu et al., 2013), however, a lot still needs to be done in exploiting the potentials of algae.

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